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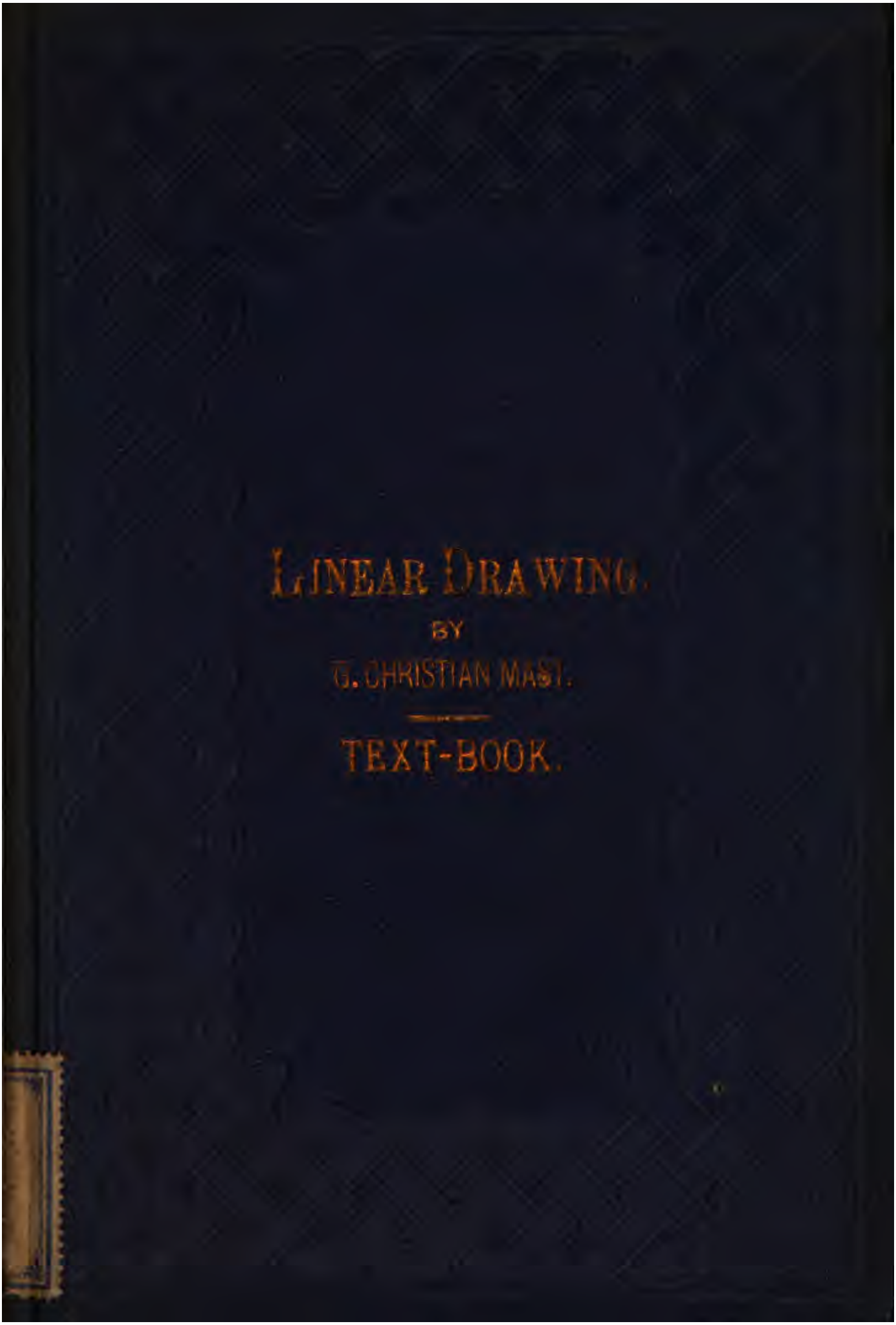

LINEAR DRAWING.

BY

G. CHRISTIAN MAST.

TEXT-BOOK.

600047121L

LINEAR DRAWING:

AN

INTRODUCTION

TO

TECHNICAL DRAWING,

CONSISTING OF

24 PLATES (4 COLOURED),

CONTAINING

100 FIGURES, GEOMETRICAL, ORNAMENTAL, ARCHITECTURAL,
ENGINEERING, MECHANICAL, &c.,

AND

A TEXT-BOOK,

GIVING COMPREHENSIVE EXPLANATIONS FOR
THE CONSTRUCTION OF THE FIGURES
AND NUMEROUS EXERCISES.

For the use of Schools and Private Students.

BY

G. CHRISTIAN MAST,

Author of "French: Practice and Theory."

TEXT—BOOK.

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PREFACE.

DURING an experience of upwards of twenty years in the work of education in this country, I have often felt the want of a good introduction to *linear drawing* for schools. The works on that subject with which I have become acquainted are, in my opinion, either too advanced and suitable only for some special trade or profession, or too elementary and uninstructive. In Germany, a practical school-book on linear drawing has been published by Herr Oberstudienrath Otto Fischer, under the title "Muster sammlung für das Linearzeichnen" (Stuttgart, J. F. Steinkopf), and has met with marked success. This work I have, however, found to be too difficult for English pupils, who, generally speaking, have not received that thorough instruction in the Grammar of Drawing which is given in German schools, and I therefore resolved to produce a similar work but of a more elementary character.

Without wishing to discuss the relative values of the various styles of drawing, I may be permitted to remark that it has always appeared strange to me that *free-hand* drawing should be considered almost the only kind suitable for young pupils, and that *linear* drawing should be deferred to a more advanced age. And yet, the latter branch appears *primâ facie* the easier of the two, as in linear drawing the pupil has for representing the various forms the use of instruments to assist the hand and the eye, while in free-hand drawing he must do without this assistance. I do not wish to discourage the practice of free-hand drawing; what I would recommend is, *the cultivation of linear drawing side by side with that of free-hand;* and to bring linear drawing within the reach of the young is the main object of this book. In composing it, I have endeavoured to render it a *simple progressive* and *pleasant introduction* to an art which has been pronounced "*the mainspring of technical education.*"

But while the work is *not* intended to be a guide to any *special* technical art, it can hardly fail to be useful to pupils of all grades of society, whatever their future occupation. For, besides acquiring a great power over their instruments, they will by the method employed in this book be forced to *close observation precision accuracy and neatness,* moral qualities not too much cultivated in schools, yet so essential for the *appreciation and execution* of superior work of any sort.

As this work is designed for the use of boys and girls of 10 or 11 years of age and upwards, the exercises begin with the most simple element—the straight line.

The first four plates, containing the easier forms of geometrical drawing, and serving as the groundwork of the following figures, answer, so to speak, to the *grammar* of the art. In Plates V. to

XIX. these elements are applied to ornamental figures and designs; in Plates XX. to XXIV., to scientific architectural mechanical and engineering objects.

In the arrangement of the figures a double gradation will be noticed. Not only is each plate, generally speaking, a step in advance of the preceding one, but in nearly all the plates containing more than one figure, these figures themselves are arranged in a progressive order. In Plates V. to VII., and also in Plates XI. to XIII., the first figure is, so to speak, the key to the rest.

The objects in the last five plates have been selected either on account of the facility with which they may be drawn, or because of their fitness in other respects. Thus, the clock and the barometer are daily before the eyes of the pupil, and the examples of original steam-engines will lead him to enquire into the very birth of the great invention of our epoch.

It is by means of careful and systematic preparation in the school-rooms throughout the country that the rising generation will be taught more fully to understand many things exhibited in our Annual International and other Exhibitions, things which are as yet to many visitors mere objects of wonder, "rare and curious," instead of means of instruction and culture.

The explanations in the text on Geography, Astronomy, Mechanics, and other branches of science are restricted to the most essential points.

The great advantage of the introduction of linear drawing into *Girls' schools*, must appear clear to any one who can see the relation of many of the designs in this book to the various artistic employments which constitute a large part of female occupation, such as embroidery, lacework, &c.

The task of the Drawing-Master will become much easier by the use of this book. Little, if anything, more will be required of him than to see that the pupil follows closely the directions of the text. This can be done by almost any teacher, and Drawing may be introduced into many schools from which hitherto it has been excluded, owing to the want of competent masters.

In the preparation of the work I have received most valuable assistance from Mr. Alfred Ewald Schmid, Assoc. Inst. C.E.

At a time when "the best means of diffusing technical instruction among the people" is declared to be the great question of the day,* I am not without hope that this work, which aims at laying the very foundation of that instruction on a broad basis by natural and approved means, will meet with a favourable reception on the part of teachers and the guides of public opinion; and that my exertion in this direction will receive the sympathy of those gentlemen and Corporations who are laudably exerting themselves in promoting the same cause, by offering prizes and other rewards to diligent students.

G. C. MAST.

148, Buckingham Palace Road,
London.
November, 1873.

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* *Vide* speech of the Earl of Carnarvon on Technical Education, at Marlborough House.

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INTRODUCTION.

1. Several sheets of drawing paper of equal size, and a little larger than the plates, should be prepared. The paper must be laid on a smooth, flat surface, for which a small drawing-board is most suitable, and fastened to it with drawing pins. For the more advanced drawings the paper should be carefully damped with a small sponge and glued to the board with *mouth* glue. A *pencil*, *ruler*, *ruling pen*, and a *pair of compasses* with a moveable limb, for placing a bow-pen or a bow-pencil, are the only instruments absolutely necessary for the construction of all the figures. The pupil may, however, use a T square, set squares, a parallel-ruler, or any other instrument that would facilitate the work.

2. From the beginning, care should be taken to place the figures and designs in a proper position on the paper. When one figure only is on a page, it ought to be placed exactly in the middle. In order to do this, draw two lines across the paper from corner to corner, intersecting each other in the centre; and through the point of intersection draw two lines at right angles to each other, and parallel to the sides of the paper. As in most figures the centre or centre line is given, or may easily be found, the position of the figures can thus be readily determined.

3. Unless specially stated, no figure is to be drawn the same size as the figure on the plate. The *first exercise* consists always in drawing the figure in accordance with the directions and dimensions given in the text; when no dimensions are given the size is optional. Except for the figures of the last four plates, the plates should not be touched with the instruments, they should only guide the eye so as to facilitate the understanding of the directions. The dimensions or size of the whole figure, or of any part of it, having been de-

termined on, the text book is a sufficient guide for constructing the figure in the same proportion as that on the plate.

4. Every figure must be drawn first with a hard pencil (H.H. or No. 3). The lines merely required in the construction, *called auxiliary* lines, must be drawn particularly light, so as to be easily taken out with India-rubber after the design is finished.

When the figure is finished in pencil, it must be inked in with Indian ink. Before inking in the beginner would do well clearly to bring out the design by making the lines of the figure a little darker than the auxiliary lines, or by marking the ends of the lines by light pencil marks. The thick lines are called *back* lines, and are generally placed at the *under* side, and on the right of the figure. The different shades may be made by lines, which is called hatching, or may be washed in in flat tints of various intensity with sepia, Indian ink, or any other colour. The coloured examples will suffice to show how other designs may be treated.

5. Advanced pupils who have had some experience in drawing should follow the order of the text. Younger pupils may safely postpone all exercises beyond the first to each figure until they have done exercises number 1. Plates V. to X. may be taken immediately after Plate II., and Plates III. and IV. be postponed, the former till after Plate X., and the latter till after Plate XVIII.

6. Should—either at the beginning or at a further stage—the pupils find the task beyond their power, the teacher is advised to smoothe the path by drawing the figures on the black board, and to explain the text which each pupil should have before him. It will also be advantageous for the pupils to reproduce, either verbally or in writing, the text from the finished drawings alone, while the more advanced draughtsmen ought to find out for themselves the elements of some of the designs, and to make the drawing quite freely after having merely read the text.

LINEAR DRAWING.

A.—PLATES I-IV. FIGURES 1-27. ELEMENTARY GEOMETRICAL FIGURES.

PLATE I.

FIGURE 1.—*A straight line and method of dividing it into various scales of equal parts.*

The line A B is a straight line. Its length is 8 inches, *English* measure, or a little more than 20 centimetres *French* measure. The eight inches on the upper side of the line are indicated by A-1; 1-2; 1-3, &c. The first inch, A-1, is sub-divided into half inches, quarters, and eighths of an inch. In the *French* system the unit of all measurements is the *metre.* Let A B C D in Figure 2 represent a line passing round our globe from pole to pole. Divide one quarter of this circumference, as A B, into ten million parts, and one of these parts is the length of a *metre.*

One-tenth of a metre is a decimetre; one-tenth of a decimetre is a centimetre; and one-tenth of a centimetre is a millimetre. On the lower part of the scale A B the fifth part of a metre is shown, and A-20 is equal to two decimetres (the one A-10, and the other 10-20), or 20 centimetres. There are marked also 10 millimetres (A-1). These French measures are written in figures as follows:—

1^{m} = one metre.
$0^{m}\cdot1$ = „ decimetre.
$0^{m}\cdot01$ = „ centimetre.
$0^{m}\cdot001$ = „ millimetre.

$1^{m}\cdot5$ is one metre five decimetres. $0^{m}\cdot25$ is two decimetres five centimetres, or, as usually read, twenty-five centimetres. $0^{m}\cdot186$ is one decimetre, eight centimetres, and 6 millimetres, or one hundred and eighty-six millimetres.

Exercises.—1. Draw a line equal to A B in length; and also another 10 inches long.

2. Draw lines 6½, 7¼, and 9¾ inches long respectively, and varying in thickness, and others also $0^{m}\cdot2$; $0^{m}\cdot15$; $6^{m}\cdot176$; and $0^{m}\cdot203$ in length.

FIGURE 2.—*The circle, circumference, arc, &c.*

The figure A B C D is called a *circle.* It is formed by turning a line O A lying on a plane completely round on one of its ends, O. The line described by the other end A, of the line O A, is called the *circumference* of the circle. A part of the circumference as B A, is an *arc.* The point O is called the *centre.* A line passing from the centre to the circumference, as O A, is a *radius* (plural radii). A line passing through the centre and terminated both ways by the circumference is a *Diameter.*

Exercises.—1. Draw circles with radii of the following lengths :—½, ¾, 1¼, and 1⅜ of an inch respectively.

2. Draw circles from the same centre, and with diameters of the following lengths :—2, 4, 6, and 8 centimetres; and others with diameters 3, 6, and 9 centimetres in length.

Note.—Circles described from a common centre, as in exercise 2, are called *concentric.*

FIGURE 3.—*Lines and Angles.*

If a straight line C D stands upon another A B in such a manner as not to incline on either side towards A B, each line, in relation to the other, is called a *perpendicular.* Lines like *a c* and *b c* that are inclined on either side are called *slanting* lines.

If a perpendicular has the direction of a plumb-line, as C D, it is said to be *vertical;* and the line to which it is perpendicular is called a *horizontal* line. The space A C D, or B C D, which is bounded by two lines standing perpendicular to each other, is called a *right* angle. Two right angles, C O B and B O A, figure 2, are also obtained by erecting a perpendicular line, O B on C A, the diameter of a circle.

An angle that is smaller than a right angle, as *c a* C, or C *c b*, figure 3, is called an *acute* angle; and one that is larger than a right angle, as A *a c*, or *c b* B, is an *obtuse* angle.

Problem—To erect a perpendicular at any point C, in the line A B.

Mark off the points *a* and *b*, making C *a* equal to C *b*. From these points as centres, and with a radius of any convenient length, describe above or below the line A B two arcs intersecting each other in *c*. Draw *c* C, and produce it to any length to D, D C will be perpendicular to A B.

FIGURE 4.—*Problem: To erect a perpendicular line at any point* C, *at or near the extremity of a line* A B.

From any point O, with the radius O C, describe a circle *a* C *b*, intersecting the line A B in *a*. Join *a* O, and produce it to the opposite side of the circle intersecting it in *b*. Draw *b* C, and produce it to any distance D, and C D will be the perpendicular line required.

Exercises: 1. See Introduction 3, page xi.

2. Draw a circle having two diameters at right angles to each other, and at their extremities erect perpendiculars on both sides; produce these perpendiculars till they meet, and a square outside the circle will be formed.

FIGURE 5.—*Another method of erecting a perpendicular* C D, *at the point* C, *in the line* A B.

From C measure off to *d* three equal parts of, say 1 inch each, taken from the scale of equal parts. From C, and with a radius equal to 4 parts, describe an arc above C, and from the point *a*, with a radius equal to 5 parts, describe another arc intersecting the previous one in *b*. Connect *b* with C, produce it to D, and C D is the perpendicular required.

FIGURE 6.—*Problem: To draw a line parallel to another line A B, at any distance from it.*

At points *a* and *b* near the extremities of A B, erect the perpendiculars *a e* and *b d*. On these lines mark off the distance at which the parallel line is to be drawn in *e* and *f*. Join *e f*, produce it to any length to C and D, and C D is the parallel required.

Note.—The figure *a b f e* is called a *rectangular parallelogram.*

Exercises: 1. Draw parallel lines at various distances.

2. Draw a rectangular parallelogram $0^{m}\cdot16$ long and $0^{m}\cdot08$ wide; and also another inside the larger at a distance of $0^{m}\cdot01$ from its sides.

3. Represent the face of a beam 12 feet long, and 1 foot wide, at a scale of 1 inch to the foot; that is to say, let every foot of length and depth in reality be represented on paper by 1 inch.

PLATE II.

FIGURE 7.—*Problem* 1: *To describe an equilateral triangle.*

Draw the line A B of the length of one of the sides of the triangle. From its extremities A and B as centres, and with a radius equal to A B, describe two arcs cutting each other in C. Join C A and C B, and A C B is the triangle required.

Problem 2: *To bisect a given straight line A B.*

Describe arcs of circles from A and B as centres, and with a radius of any length not less than half the given line A B, intersecting each other in *a* and *b* above and below A B respectively. Join *a b*; this line will bisect A B in point *c*, and be also perpendicular to it.

Note. By repeating the above process with the parts of A B, a line may be divided into 4, 8, 16, &c., equal parts.

Exercises: 1. Draw a line 7 inches long and divide it into 8 equal parts.

2. Draw an equilateral triangle, the side of which is 3 inches long; bisect each side, and from the points of bisection draw lines to the opposite angles. If the figure has been correctly drawn, all these lines will intersect each other in one point within the triangle, and will be perpendicular to the sides of the triangle.

FIGURE 8.—*Problem: To draw equilateral triangles between two given parallel lines,* A *f and a* F.

On the line A *f* measure off any distance A *n*. Upon A *n* construct an equilateral triangle, A *n o* and produce the side A *o* till it meets the line *a* F in C, make A B equal to A C, and join C B, A C B, is one of the triangles required. Bisect A B in *b*, and from the point C mark off on both sides the distances C *a* and C *c*, each equal to A *b* or *b* B. Join *a b* and *b c*, and *a b c* will be one of the triangles of the inverted series. To complete the figure requires no further guidance.

Exercise: Construct equilateral triangles between parallel lines at a distance of 3½ inches from each other.

FIGURE 9.—*Problem (a): To construct a square on any given line* A B.

At the points A and B erect perpendiculars A *a* and B *b*, make A C and B D equal to A B; join C D, and A B C D is the square required.

Problem (b): To divide a square into two eqnal parts.

1. Draw from the angle C a line to the opposite angle B of the square, and A C D, and A B D, will each be half of the square. In like manner the line A D will divide the square into two equal parts, A C D and A B D.

Note.—The lines C B and A D are called *diagonals.*

2. Bisect A B and C D in *i* and *k*, join *i k*, and it will divide the square into two equal parts, A *i k* C and *i* B D *k*. In like manner will the square be bisected by the line *m n*, erected perpendicularly on A C at the point obtained by bisecting A C.

Exercises: 1. See introduction 3.

2. Construct a square upon a line $0^{m}\cdot18$ long. Inside it and parallel to its sides draw, at a distance of $0^{m}\cdot03$, a smaller square; construct a third one inside the second and under similar conditions; bisect the sides of the inner square and at the points thus obtained erect perpendiculars to the sides of the outer square.

3. Draw a plan of the following, at a scalc of one-eighth of an inch to a foot. I have a square piece of ground, the side being 90 ft. long. In the middle of it I wish to erect a building 30 ft. square Around the inside of the boundary of the ground and around the building I wish to have paths 5 feet wide; and also four paths, each 6 feet wide, leading from the middle of each boundary line to the middle of each wall of the building.

Figure 10.—*A chess-board.*

Draw the square A B C D of any required size. Divide it into four equal squares, as in 2, previous Fig.; each of these divide again into as many parts, repeat this operation, and sixty-four equal parts will be obtained.

The same result may be obtained by dividing each side of the square A B D C into eight equal parts, and drawing lines from the points of division parallel to the sides of the square.

Note.—The number of smaller squares obtained is equal to the square of the number of parts into which the side of the original square has been divided; in the above example it is 8 × 8 = 64. If the square be bisected by a perpendicular on A B, at a point half-way between A and B, the number of smaller squares in each half would be 32, obtained by the multiplication of the numbers into which the respective sides have been divided, that is, 4 × 8 = 32. The results obtained as shown in this note form the basis of all *surface* or *area* measurement.

Exercises: 1. See introduction 3.

2. Draw a chess-board measuring 64 square inches, and having a border round it half-an-inch wide. The board thus drawn is half the length of that in common use; state in what proportion the surface of the latter stands to that drawn in this exercise.

FIGURE 11.—*Problem: To divide a line into three, or any other number of equal parts.*

Let A B be a line to be divided into—say, three equal parts. From either of its extremities, say from B, draw a line B C making an acute angle with A B. Upon it measure off any three equal parts, beginning at B, as B-1, 1-2, 2-3. Draw A 3, and through 2 and 1, lines parallel to A 3, meeting A B in *b* and *c*, and the line A B is divided into three equal parts in the points *b* and *c*. To divide A B into five, seven, or any other number of equal parts, proceed as above, marking off on B C the number of parts into which it is required to divide A B.

Exercises: 1. Divide a line $0^{m}\cdot16$ in length into five equal parts; give the result also in figures (French measure).

2. Divide a square 6 inches long into 49 equal squares, and express the area of the whole in square inches.

3. A square is divided into 81 equal parts, its area is 81 square inches, how long is the side of each of the smaller squares?

PLATE III.

FIGURE 12.—*Problem* 1: *To inscribe an equilateral triangle in a circle.*

Let the circle be A B C. Draw the diameter, *a* C. With the radius as *a* O describe, from the point *a*, the arc of a circle, A O B, intersecting the given circle in the points A and B. Join A B, B C, and C A; the triangle A C B is the equilateral triangle required.

Problem 2: *To describe a regular hexagon (a six-sided figure) in a circle.*

Find the points A, C, and B as in the previous figure. Join A *a* and B *a*. From C mark off C *c* and C *b*, each equal to *a* A or *a* B. Join C *c*, *c* A, and C *b*, *b* B, and A *a* B *b* C *c* will be the required hexagon.

Problem 3.—*To circumscribe a regular hexagon about a given circle.*

Construct a regular hexagon within the circle. Bisect the sides of this hexagon as shown on the side A *a*, which is bisected in *d*. From the centre O, draw O *d* and produce it to the circumference at *e*. Obtain in a similar manner all the points *e*, and through them draw lines parallel to the sides of the inscribed hexagon, meeting each other in *f g h i k l* respectively; a regular hexagon outside the circle will thus be formed.

Exercises: Construct inside a circle whose radius is $0^{m}{\cdot}065$ long. First, an equilateral triangle; second, a regular hexagon; third, outside the circle construct a regular hexagon. Express in words and figures the length of the diameter of the circle?

Figure 13.—*Problem* 1.—*To inscribe a square in a given circle.*

Let *a b c d* be the given circle. Draw two diameters, *a b* and *c d*, at right angles to each other; join *a c*, *c b*, *b d*, and *d a;* the figure *a c b d* is the required square. If the square is required to be in the position of A B C D, bisect the angles formed by the diameter *a b* and *c d;* produce the lines of bisection to the circumference, meeting it in the points A B C D. Join these and the required square is obtained.

Problem 2.—*To describe a square about a given circle.*

(*a*) Draw the inner square A B C D, obtain the points *a b c d* as the points *e* were found in figure 12, 3. Through these draw lines parallel to the sides of the square, and the external square E F G H will be formed.

(*b*) Or if the inner square A B C D be not drawn, let the two diameters, *a b* and *c d*, be drawn at right angles to each other. From the points *a c b d*, and with a radius *a* O of the circle, draw arcs intersecting each other in E F G H. Draw E F, F G, G H, and H E passing through the points *c b d a;* the square required is E F G H.

Exercises: 1. See Introduction 3.

2. Draw a circle with a radius of 3 inches. Construct squares inside and outside of this circle in the position of A B C D, and of E F G H. Inside the smaller square draw a third one at a distance equal to that of the outer square from the first inscribed square.

3. A lady has a round table, with a diameter of 2 feet. She wishes to have a chess-board made, the corners of which must coincide with the circumference of the table, when laid exactly on the middle of the latter. The border round the board is to be about one-eighth of the entire width of the board. Draw a model of the table with the chess-board upon it at a scale of 3½ inches to the foot.

FIGURE 14.—*Problem* 1 : *To inscribe a regular octagon* (*an eight-sided figure*) *in a given circle.*

Draw two diameters, *a b* and *c d*, at right angles to each other. Construct the square *e f g h* about the circle. Draw the diagonals, *e g* and *f h*, cutting the circle in the points *i k l m*. Join *a m*, *c l*, *b k*, *d i*, and the octagon required is formed.

Problem 2 : *To describe a regular octagon about a circle.*

Draw the diameters, *a b* and *c d* ; construct *e f g h*, and draw its diagonals *e g* and *f h*. At *i k l m* erect lines on both sides of the diagonals and at right angles to them, meeting the sides of the square *e f g h*, and *n o p q r s t u* is the regular octagon required.

Exercise : 1. Construct similar octagons inside and outside a circle with a radius of $0^{m}\cdot07$.

FIGURE 15.—*Problem* 1 : *To inscribe a regular pentagon* (*five-sided figure*) *in a circle.*

In any circle draw the diameters, *a b* and A H, at right angles to each other. Bisect O *a* in *e*. From *e* as a centre with the radius *e* A, describe an arc cutting the diameter *a b* in *f*. From A as centre, with the radius A *f*, describe the arc *f c*, cutting the circumference of the circle in B. Join A B, which is one of the sides of the pentagon. To complete the figure, mark off the sides B C, C D, D E, E A, each equal to A B.

Problem 2 : *To inscribe a regular decagon* (*ten-sided figure*) *in a circle.*

Inscribe a regular pentagon as above described. Bisect each of the sides in *g*, *h i*, *l k*. Through these points draw from the centre O· radii, meeting the circumference in the points F G H I K. Join A F, F B, &c., which will complete the decagon.

Exercises: 1. Construct a regular pentagon and a regular decagon, inside a circle with a diameter of 4$\frac{5}{8}$ inches.

2. Construct a pentagon inside a circle with a radius of $0^{m}\cdot051$, and construct also another outside with its sides parallel to those of the inner pentagon, touching the circle in points corresponding to F, G, H, I, K. Radii O A, O B, O C, &., produced will give the limits of the sides of the circumscribed pentagon. In a similar manner a decagon may be constructed outside a circle.

FIGURE 16.—*Problem: To construct a regular pentagon, the length of one side being given.*

Let A B be the given side. Bisect it in *a*. At the extremity B, erect the perpendicular B *c* equal to A B. Produce A B through B. From *a* as centre, and with the radius *a c*, describe an arc intersecting A B produced in *b*. From the points A and B as centres, and with the radius A *b*, describe two arcs intersecting each other in D. From the points A B and D as centres, and with the radius A B, describe arcs intersecting each other in C and E. Join B C, C D, D E, and A E, and the required pentagon will be formed.

Exercise.—In the same manner as above draw a regular pentagon, the side of which is to be 2 inches in length.

FIGURE 17.—*Problem: To construct a regular hexagon, the length of one of its sides being given.*

Let A B be the given side. From its extremities A and B as centres, and with A B as radius, describe arcs intersecting each other in O. From the point O as centre, with the radius O A or O B, describe a circle; upon the circumference of this circle mark off divisions with the radius O A, and the angles of the required hexagon will be formed; join these points for the hexagon.

Exercise.—Draw a hexagon in the same manner as above, a side of which is ·045 in length, and upon it describe a dodecagon (See figure 15.)

FIGURE 18.—*Problem: To construct a regular octagon, one side being given.*

Let A B be the given line; produce it indefinitely to *a* and *b*. At the points A and B erect perpendiculars of indefinite length, namely, A *c* and B *d*. From the points A and B as centres, and with the radius A B, draw arcs intersecting A *a* and A *c* in *n*, and B *b* and B *d* in *m*. Bisect these arcs in the points H and C; from these points draw H G and C D parallel to A *c* and B *d*, and equal to A B. From G and D as centres draw arcs cutting the perpendiculars A *c* and B *d* in F and E. Join G F, F E, and E D to complete the octagon.

Note.—The centre of this figure is the intersection of two diagonals, as of A E and B F, in O.

Exercise.—Construct an octagon in the same manner as above, the length of one of its sides being 45 millemetres. Describe a circle about it, and outside this circle an octagon parallel to the smaller one.

FIGURE 19.—*A Circular Protractor* (an instrument for measuring angles.)

The circumference of a circle being divided into 360 equal parts, and lines or radii being drawn from the centre to these points of division, the space, or angle contained between any two of these radii, is called a *degree*. Each degree is subdivided into 60 parts called minutes, and each minute into 60 seconds. The signs or exponents of these measurements are ° ′ ″ respectively: for example, 45° 30′ 25″ reads, 45 degrees, 30 minutes, 25 seconds.

From the centre O with the radii of 2½ and 2 inches, describe circles for the outer and inner edges of the protractor. From the same centre, with radii of 2¼ and 2⅜ inches, describe two other circles between which the divisions are to be marked.

Draw the diameter A B, and at right angles to it another diameter; the circle is thus divided into quadrants, each containing one-fourth of the number of degrees in the whole circle, that is, 90°. Divide each of these quadrants into 9 equal parts, and each of these parts will contain 10°, each of which must again be divided into 10 equal parts, to obtain the size of 1°. The figure in the plate being small, only a portion of the subdividing has been carried out.

The degrees are numbered in two directions, beginning with zero at A and going completely round the circle towards the right; and beginning also with zero at B and going round in the contrary direction, in each case numbering at every 10 degrees. *a b c d* represents "the stiffening bar" with its edge *a b* coinciding perfectly with the diameter of the circle passing through the zero divisions. This bar is feathered down to the edge *a b*, so as to be more easily applied to any line. At the centre O a little notch will be observed; this is made that the point of coincidence of the two lines forming the angle to be measured may more readily be observed. Protractors are also made with the divisions marked for half the circle only, that is to say, from zero to 180. In this case the instrument is limited by the lower line *c d* of the stiffening bar, produced to the circumference of the outer circle.

Exercise.—Construct a similar protractor with a diameter 20 centimetres in length, making the width of the ring and stiffening bar 2 centimetres.

FIGURE 20.—*The mode of measuring an angle by means of a protractor.*

Let B A C be the angle to be measured. Should the lines A B and A C be shorter than the radius of the protractor, produce them to a sufficient length towards *b* and *c*. To obtain greater accuracy it is desirable, when possible, to produce them also in the opposite direction towards *d* and *e*. To measure the angle lay the protractor on either of the lines, say on A C, in such a manner that its centre, O, coincides with the angular point at A, and that the edge *a b* of the bar of the instrument lies evenly on the line A C, and so that its zero point falls on the line A E, or A C produced. Then, counting to the left, read off the degrees corresponding to the line A B, or A B produced. In the present instance the measurement of the angle is 90°, or a right angle, as marked on the diagram.

If the angle is measured from the line A B the protractor must be laid on this line, and the degrees counted from left to right.

Note.—Regular polygons of any number of sides may be rapidly constructed by means of this instrument. The angle required is found by dividing 360° by the number of sides in the required polygon. To construct, for example, an octagon within a circle, as in figure 14, by means of the protractor, obtain the angle required by dividing 360° by 8 = 45°. Mark off on the circumference of the circle every 45° in the points *a, m, c, l, b, k, d, i,* &c. Join *a m, m c,* &c., and a regular octagon will be formed.

PLATE IV.

FIGURE 21.—*To construct an oval, the two diameters being given.*

Let A B and C D be the two given diameters. Place them at right angles so as to bisect each other, as in figure 21. The point of intersection O will be the central point of the oval. From O mark off O *a* towards A and B, each equal to O D or O C. Draw the lines D A, D B, and C A, C B. On them mark off D *b* and C *b* equal to A *a* or B *a*; bisect the distances A *b* and B *b* in the points *d*, and through these draw lines at right angles to A D, D B, B C, and C A, intersecting each other in the points 1. Make 1 *c* equal to 1 A or 1 B, and these lines will be the radii of the arcs *c* A *c* and *c* B *c* from the centres 1. Produce the lines *c* 1 till they intersect in points, 2 which will be the centres, and 2 *c* the radii, for describing the arcs *c* D *c* and *c* C *c*.

Exercise.—See Introduction 3.

FIGURE 22.—Problem: *To describe an oval of a given length and breadth, so that one half of the small arcs shall contain an angle of* 45°.

Let A B and C D be the given length and breadth. Place them at right angles and bisecting each other in O. From the centre O with the radius O A or O B describe a circle passing through the points A and B. Produce the smaller axis C D to the points *c* and *d*; the circle will thus be divided into four equal parts. Bisect each quadrant in the points *a* by the lines *a* O. These lines bisect the angles A O *c*, &c., which are right angles, and therefore the angles A O *a* and *a* O *c* are each half a right angle, or 45°.

Draw the cords A *a*, *a c*, &c. From the point C draw a line parallel to *a c*, meeting A *a* in the point *b*. From *b* draw a line parallel to *a* O, meeting the axis A B in the point 1. The line *b* 1 being parallel to *a* O, the angle *b* 1 A is an angle of 45°. The point 1 is the centre, and the line *b* 1 the radius of the small arc. To find the centres for describing the large arcs, produce the radii *b* 1 to the points 2 in the axis C D, and these points are the centres of the arcs passing through the points C and D.

Exercise.—See Introduction 3.

FIGURE 23.—*To construct an oval, in which the angle contained by the smaller arcs are* 120°, *the diameter being given also.*

Let A B and C D be the given diameters. Bisect A B in O. From O as centre, and with the radius O A, describe a circle. On its circumference mark off from A and B, with the radius A O, the arcs A a and B a, on both sides of A B. Draw the two diagonals a a as shown by the dotted lines. These lines divide each semicircle into three equal parts, therefore the angle A O a is equal to $\frac{180}{3} = 60°$, and therefore the diameters a a are at an inclination of 60° to A B. Produce D C to c and d on the circumference. Join A a, B a, a c and a d. From the points C and D draw lines parallel to c a and d a, meeting the lines A a and B a in b, which are the points of junction of the larger and smaller arcs of the oval. From b draw lines parallel to the dotted lines a a, intersecting each other in the points 1 in the major axis A B, and in points 2 in the minor axis C D produced. These lines being parallel to a a, are, like the latter, at an inclination of 60° to the axis A B. The points 1 are the centres, and the lines 1 b the radii of the smaller arcs b, A b, and b B b, comprising an angle of twice 60° = 120°; and the points 2 are the centres, and the lines 2 b the radii of the larger arcs b C b and b D b.

Note.—By comparing the oval of figure 23 with that of figure 22 in both of which the length and breadth are identical, it will be observed that, by increasing the angle of the smaller arcs, the ends of the oval become more ample.

Exercises: 1. See Introduction 3.

2. At a scale of ¼ of an inch to a foot draw, in a rectangular grass plot, 13 ft. wide and 33 ft. long, a plan according to the following instructions. In the grass plot are three flower beds. The centre bed forms a circle of 9 ft. in diameter, and the two side beds are ovals, as described in figure 23; their major axes, 9ft. long, or equal to the diameter of the centre bed, and placed so that their major axes run parallel to the smaller sides of the rectangle. The distance between the border of the centre bed and that of the side beds is 4ft.

Figure 24.—*To construct an oval in which the long axis* A B *is equal to any four units of measure, and the short axis* C D *equal to three units of the same measure.*

Divide the long axis A B into three equal parts in the points 1. On the part between the points 1 construct an equilateral triangle on both sides, obtaining thus the points 2. Produce their sides to the points *a*, making 1 *a* equal to one of the sides of the equilateral triangles. From the centres 1, and with the radius 1 *a* describe the small arcs *a* A *a*, and *a* B *a* ; and from the centres 2, and with the radius 2 *a* describe the arcs *a* C *a* and *a* D *a*.

Exercise: See Introduction 3.

Figure 25.

The term "*oval*" meaning egg-shaped, Fig. 25, is given to show the exact shape of an egg and the manner of drawing it.

Divide the length of the egg, indicated by the line A B, into three equal parts. Mark the point of division next to A by 1, and from it as centre, and with the radius A 1 describe a circle. By bisecting the lower third of A B, you obtain the centre 2, as well as the radius 2 B of the smaller circle. Through the point 1 draw the line 3-3, at right angles to A B, making the distances 1-3 equal to the diameter of the larger circle, and cutting its circumference in C and D. From 3 draw lines through the centre 2, and produce them to the points *a* on the circumference of the smaller circle. From 3 as centres, and with the radius 3 *a*, describe the arcs *a* D and *a* C.

Exercises: 1. See Introduction 3.

2. Measure the length of any egg, and draw its outline by the above method.

Figure 26.—*An egg-cup with an egg in it.*

The points 1, 2, and 3 are obtained as in Fig. 25. Both the dotted arcs and those parallel to them, forming part of the cup, are drawn from the centres 3. To get the points 4, the centres of the small arcs, make the distance 2-4 equal to one-third of the length of the egg. The lower part of the egg-cup needs no further guidance for its construction, and may be varied by the pupil.

Exercises: 1. See Introduction 3.

2. Put an egg into an egg-cup, and make a sketch of it by the above method.

FIGURE 27.

In the ovals of the figures 21, 22, and 23, the proportion of the longer to the shorter axis is as three to two. If the shorter axis is less than two-thirds of the larger, the above methods are not admissible, because the arcs, at their points of junction, would make the impression of jarring. To avoid this, such ovals must be constructed from five, seven, or more centres. Fig. 27, an oval in which the larger axis A B is nearly twice as large as the smaller C D, is an example. It is constructed from five centres.

Divide the axis A B into six equal parts, thus obtaining the points 1, *a*, E, *a*, 1. On both sides of the distance between 1 and 1 erect the equilateral triangles 1 *b* 1. Through the points *b*, E, *b*, draw the line *c d* indefinitely. Produce the lines *b* 1 to *e*, making 1 *e* equal to 1 A or 1 B. The points 1 are the centres, and 1 *e* the radii, of the arcs *e* A *e* and *e* B *e*. From the points *b* mark off towards *d* and *c*, distances equal to one of the divisions of A B, to obtain the points 3. From these points draw lines to *a* and produce them to *f*, making 2 *f* equal to 2 *e*. Through the intersection of those lines with 1 *b*, the points 2 are obtained. From these points as centres and with the radius 2 *e*, describe the second arcs *e f*, and from the centres 3, and with the radius 3 *f* describe the arcs *f* C *f* and *f* D *f*.

Note.—The figure as described above is a near approach to an , the construction of which is described in Plate XX., Fig. 83.

Exercises: 1. See Introduction 3.

2. Draw a plan, according to the following instructions, and at a scale of $\frac{1}{4}$ of an inch to the foot, of a garden which is 46 feet long and 31 feet wide. All round the garden is a path 5 feet wide, and within the enclosed rectangle an oval, the longer axis of which is 30 feet long, as in Fig. 27. From the extremities of the smaller axis of the oval is a path 5 feet wide, communicating with the outer path in such a manner that half of it lies on either side of the smaller axis produced. In the middle of the oval is a circular fountain, 5 feet in diameter. A path, 5 feet wide, encircles this basin, and one 4 feet wide is inside the oval. Care must be taken to stop the lines at their intersection with each other, forming thus a flower-bed on each side of the fountain.

B.—PLATES V.–XIX. FIGURES 28-79. APPLICATION OF GEOMETRICAL FIGURES TO VARIOUS ORNAMENTAL DESIGNS.

PLATE V.

Note.—In all the figures of this plate straight lines and squares form the elements of the designs, and of the division of the various parts.

FIGURES 28 TO 32.—*Easy studies on the application of the square.*

For the construction of these figures the pupil is referred to the "Introduction," beyond which he requires no further guidance.

FIGURE 33.

Draw *a b* of an indefinite length. At *a* erect a perpendicular *a c* of a given height. Divide *a c* into three equal parts in *f* and *g*. Through *c*, *f*, and *g* draw lines parallel to *a b*. On *a b* set off one of the divisions of *a c*, seven times, to obtain the points 1, 2, 3, 4, 5, 6, 7. From these points draw parallels with *a c* to *c d*. For the rest of the construction follow the directions in the Introduction.

Exercises: 1. See Introduction 3.

2. Draw the same figure, making the sides of the small squares two centimetres long, and repeat part of the design towards the side indicated by the dotted lines, so as to make its total length 22 centimetres.

FIGURE 34.

On a line *a b* of indefinite length erect the perpendicular *a c* of any desired length. Divide it into five equal parts in the points *e*, *f*, *g*, *h*. Through these points and through *c* draw parallels to *a b*. On *a b* and *c d* set off any number of parts—say 13—each equal to one of the divisions of *a c*, and mark them by the figures 1, 2, 3, &c. Draw lines from 1 to 1, 2 to 2, &c.; count carefully the number of divisions required to form the design, pencil it in and ink it over as directed in the Introduction. This, like the previous figure, may be continued to any length.

Exercises: 1. See Introduction 3.

2. Make one of the squares half an inch, and the whole design the length of the paper.

FIGURE 35.

Draw a line *a b* of any required length. At one of its extremities erect the perpendicular *a c*. On both lines mark off any number of equal parts, 1, 2, 3, &c., towards *b* and *c*, and draw lines through the points 7 parallel to *a b* and *a c*, thus obtaining the lines 7 *e* and 7 *f* intersecting each other in *d*. The lines *d e* and *d f* (continued) form the *inside border line.*

Through all the divisions 1, 2, 3, &c., on *a c* and *a b* draw lines parallel to the latter ones, taking care to limit them beyond the 7th division, at their junction with the inside border lines. To facilitate the construction of the parallel lines beyond the 7th division, mark off from *d* the divisions 8, 9, 10, &c., on *d e* and *d f*, taking care to number the first division on both lines by 8. To complete the design follow previous instruction.

Exercises: 1. See Introduction 3.

2. Draw another complete border, parallel to the sides of your paper, the length *a b* to be divided into twenty-five equal parts of

1 centimetre each, to be marked 1, 2, &c., to 24; and the line *a c* into twenty-one parts of equal length, to be marked 1, 2, 3, &c., to 20.

Note. The figure can be made to any length and width, but the lines of division must always be a multiple of 4, plus 1, as twice 4, + 1 = 9, or three times 4, + 1 = 13, &c.

FIGURE 36.

The mode of constructing this figure is similar to that of the former; but the lines *b e* and *c f*, indicating the breadth of the border, must be divided into five equal parts, and *a c* and *a b* into any multiple of 4, plus 1 parts. If the figure is not complete, it can be broken off at any number of divisions, as in 10 and 14, in Figure 36. The double lines must be drawn at a distance of $\frac{1}{4}$ of one of the equal divisions.

Exercises: 1. See Introduction 3.

2. Draw a complete border parallel to the sides of your paper, length 13 divisions, and width nine divisions, of $\frac{3}{4}$ of an inch each.

PLATE VI.

The *element* of all the *designs* of this plate is the *equilateral triangle.*

FIGURE 37.—*Divisions of the equilateral triangle.*

Draw an equilateral triangle *a b c* of any size. Divide each of the sides into five, or any other number of equal parts (see Fig 11), d through these points draw lines parallel to the sides.

FIGURE 38.—*A lozenge and its divisions.*

On each side of the line *b d*, of any length, construct the equi lateral triangles *b a d* and *b c d*. Divide the lines *a b*, *b c*, into any number of equal parts, and through the points thus obtained draw lines parallel to the sides of the figure. The smaller figures thus obtained are similar to the whole figure, and are called *lozenges.* The square of the number of parts into which each line is divided, gives the number of smaller lozenges obtained; in our figure 5 × 5 = 25.

Exercises: 1. See introduction 3.

2. Construct a lozenge by the above method, the side of which is 3 inches long, and divide it into 49 smaller ones.

FIGURE 39.—*A frieze.*

Let the breadth be *a n*. At right angles to it draw parallel lines to any indefinite length. Divide *a n* into four equal parts, 1, 2, 3, and through these points draw lines parallel to those first drawn. Beginning at *a*, construct between the outer parallel lines a system of equilateral triangles *a b c*, *c d e*, *e f g*, *g h i*, as explained in Fig. 8, Plate II. Divide all the bases in the lower and in the upper lines into four equal parts, in the points 1, 2, and 3, taking care to number them as in the figure, beginning with number 1 after the letters *a*, *b*, *c*, &c. Draw lines parallel to the sides of the triangles from 1 to 1, 2 to 2, 3 to 3, and finish the figure according to previous instructions.

Exercise. See Introduction 3.

FIGURE 40.—*A frieze.*

The construction of this figure is similar to that just described. The height *a n*, however, is to be divided into six equal parts, to be marked 1, 2, 3, 4, and 5; also the bases of the triangles *a b c*, *b c d*, &c., must be divided into the same number of parts, and marked off by the numbers 1 to 5, beginning after the letters *a*, *b*, *c*, &c.

Exercises: 1. See Introduction 3.

2. Draw a similar figure 4 inches wide.

PLATE VII.

Ornamental designs for various purposes, their foundation being the circle.

Figure 41.

Draw the centre line *a b*. Set off the width *g h*, putting half on each side of *a b*; draw *h i* and *g k* parallel to *a b*. Mark off the distance *a* 1, equal to *a g* or *a h*. Through the point 1, which is the centre of the first circle, draw the line 1 *m* parallel to *g h*. Divide 1 *m* into 6 equal parts, and describe the larger circle with the radius 1 *c* equal to five of those parts, and the smaller, with the radius 1 *e* equal to three of those parts. Then set off on *a b*, the distance 1 *c*, to obtain 2, 3, 4, &c., to 10, the centres for the other rings. The radii for all these are the same as those of the first ring. In inking in, care must be taken to stop the lines at the points where the rings are shown to pass under each other.

Exercise: Draw a similar figure, making the breadth of the band 8 centimetres.

Figure 42.

Draw the centre line *a b*. Through *a* draw *c d* at right angles, making *a d* equal to *a c*. Through *d* and *c* draw *d e* and *c f* parallel to *a b*, and mark off on them the lengths *d h* and *c g*, equal to *a c*; *h* intersecting *a b* in 1, which is the centre of the first of the tric circles. Divide 1 *h* into five equal parts, describe the inner circle with the radius 1 *i* equal to one part; the second circle with 1 *k* as radius equal to two parts, and the third with radius 1 *l* equal to four parts, leaving the distance *l h* for the double line of the border. The distance between the centres 2, 3, &c., to 9 is 1 *a*. To complete the figure proceed as in the previous example.

Exercise: For drawing the above design make the distance *c d* equal to 3⅛ of an inch.

Note. Both in this and in the exercise to the following figure great care must be taken that the circles at their points of touching coincide. Their meeting at the exact point depends, of course, on the accuracy with which the various radii are measured off.

FIGURE 43.

Draw the lines *a b* and *c d*, and the parallel lines *d e* and *c f* as in the preceding figure, and *g h* at a distance *a c* from *c d*. Divide 1 *h* into six equal parts, and set off on *a b* the centres 2, 3, 4, &c., at distances from each other equal to 1 *h*.

Describe the circles with the radii 1 *i*, 1 *k*, 1 *l*, equal to one, three, and five, of the divisions of 1 *h* respectively, leaving one part for the breadth of the border round the design. The centres of the small outer circles are all at a distance of four parts from the centre line *a b*, and lie on lines drawn through the points 2, 4, 6, and 8, at right angles to *a b*. These circles have the radius 1 *i*.

Exercise: Draw the design, making the breadth *e d*, 9 centimetres.

PLATES VIII. TO X.

Designs for ornamental paving or panel.

PLATE VIII.

FIGURE 44.

Draw the rectangle A B C D, making the length of A B and C D equal to 37, and that of A D and B C equal to 25 equal parts. Mark the points of all these parts, but number only those which are numbered on the plate. Through the numbered points draw lines parallel to each of the sides, to the corresponding opposite numbers, from 1 to 1, 3 to 3, &c. Count off the points of intersection of the lines forming the design, and finish it according to the directions in the Introduction. The distance of the narrow parallel lines must be half of one of the divisions of the sides of the rectangle. It will be noticed that some of these must be drawn above, others below, some to the left, others to the right, of the numbered lines.

Exercise: Draw the above, making one of the 37 and 25 equal parts a quarter of an inch long.

PLATE IX.

Figure 45.

With the exception of making the sides of the rectangle A B C D equal to 31 and 25 equal parts respectively, proceed in exactly the same manner as in the previous figure.

Exercise: Draw the design, making one of the 31 and 25 divisions equal to 8 millimetres.

PLATE X.

Figure 46.

d in drawing the rectangle A B C D 43 equal parts long,
the same parts wide, finding the points 1, 3, 4, 6, 7, &c.,

and drawing the auxiliary parallel lines, as in the two previous figures.

The points *a, b, c, d,* for the inner rectangle are obtained by the intersection of the four parallel lines drawn from the points 10 on A B and A D from the points 33 on A B and 21 on A D. On the lines *a b* and *c d* number all the points from 11 to 32, and from 11 to 20. For the completion of the figure proceed as in the two previous numbers.

Note. It will be seen that the design of the border of this figure is the same as that described in Fig. 35. In Fig. 46 the border is complete, while in Fig. 35 only a part of it is given.

Exercises: 1. See introduction 3.

2. Draw a design like that of Fig. 46, making it 301 centimetres long and 217 millimetres wide. By dividing the length and width required by 43 and 31 respectively, we obtain the length of one of the equal parts—namely, seven millimetres.

3. Draw a complete border by the method given to Fig 35, and vary the pattern of the inner rectangle *a b c d,* adapting it to the altered circumstances.

PLATE XI.

FIGURES 47–49.—*Application of the square and the regular octagon to ornamental purposes.*

FIGURE 47.

Construct the squares A B C D and E F G H, within a circle, and the square *a b c d* without it (see Fig. 13 Plate III.) By the intersection of the sides of the squares A B C D and E F G H, the octagon *e f g h i k l m* is formed. From the centre o describe a circle with a diameter equal to half of one of the sides of the octagon, and from the angles of the octagon *e f g h*, &c., draw lines to the centre, stopping them at the circumference of the small circle, thus forming a Maltese cross within the octagon.

Exercise: Draw the above, making the diameter of the circle 102 centimetres long.

FIGURE 48.

Draw the square *a b c d* and its diagonals, and construct within it the two intersecting squares A B C D and E F G H, as in the previous figure. Draw also the diagonals of these squares, and through the points of intersection of the sides of both squares with their diagonals, draw the lines *e f*, *f h*, *h g*, *g e*; and *i k*, *k e*, *l m*, and *m i*, stopping each line (in inking in) at the point where one square intersects the other. An octagon is thus formed, within which draw the German iron cross as in the plate. Draw the square *c d e f* together with the rest of the figure in a similar manner, only varying the design in the centre, as shown.

Exercises: 1. Draw the above, making the width *a b* 4 inches in length.

2. Draw three squares instead of two only, repeating that of *a b c d* on the right hand side of the figure, with a width *a b* of 8 centimetres.

FIGURE 49.

Draw the centre line *a b*, and the rectangle *c e f d* in the same manner as above described. On the lines *e f* and *c d* mark off, beginning at *e* and *c*, the distances *e* to 1, 1 to 2, 2 to 3, &c., each equal to *a e* or *a c*. Draw through the points 1, 2, &c., lines parallel to *e c*, intersecting *a b* in *n* and *m*, the centres of the circles. Divide *a e* into five equal parts, and draw the smaller circles from *n* as centres with radii equal to 1 and 2 parts of *a e*, for the inner and outer lines respectively; and describe the larger circles from *m* as centres, and with radii equal to 3 and 4 parts of *a e* for the inner and outer lines respectively. To obtain the outside lines of the squares draw lines from 1 to *a*, from 1 through *m* to 3, from 3 through *m* to 5, &c. The inner lines must be parallel to these at a distance of 1 part of *a e*, stopping them at their intersection with the lines 1 *n* 1, 2 *m* 2, &c. The distance of the inner double lines, both for the circles and for the squares is equal to one-fourth of one of the parts of *a e*.

Exercises: 1. See Introduction 3.

2. Draw the design again with a width of 3½ inches, but finish it off so as to make the end within the rectangle 5 *f d* 5 correspond to the beginning within the rectangle *e* 1 1 *c*.

PLATE XII.

FIGURES 50 to 54.—*Various designs of which the equilateral triangle, the regular hexagon, and dodecagon are the elements.*

FIGURE 50.

Within a circle of any diameter draw the hexagon A *a*, *b* C, *c d*. (See figure 12, Plate III.) Join every two alternate points by the lines A *b*, *a* C, *b c*, C *d*, *c* A, and *d a*, forming thus two equilateral triangles, A *b c* and *a* C *d*, which, by the intersection of their sides form the exterior hexagon *e f g h i k*. Join each two opposite angles of this hexagon by the lines *e h*, *f i*, and *g k*, all passing through the centre O.

Exercise.—See Introduction 3.

FIGURE 51.

Draw the centre line *g h*, and the line *a c*, of any given length, at right angles to it, making *g c* equal to *g a*. Through *c* and *a* draw lines parallel to *g h*, and between them construct the equilateral triangle *a e f*. (See figure 8, Plate II.) Make *g n* equal to *a f*, and draw *f k* parallel to *a c*, passing through *n*.

Bisect *a f* in *i*, and draw *i e* bisecting *g n* in 1. From 1 as centre, and with the radius 1 *g*, describe the circle *g o n p;* and within it construct two equilateral triangles, *g t u* and *s n v*, as in the preceding figure.

Bisect all the sides of these triangles in the points *x*, by drawing the lines *s x*, *b x*, &c., towards the centre 1, and draw the interior lines *x y y* parallel to the sides of the equilateral triangles, thus forming the hexagon *y y y*, &c.

Continue two of the interior lines towards the line *k f* to *z*, and the first portion of the figure is finished. For the second portion make *n* 2 equal to *n* 1; describe from point 2, and with the radius 2 *n*, the circle *n q h r*, and proceed as before. By finding also points 3, 4, 5, &c., in a similar manner as point 2, the design may be continued to any required length.

Exercises: 1. See Introduction 3.

2. Make the line *a c* 8 centimetres in length, and draw three instead of two of the portions.

FIGURE 52.

Describe the square A B C D; inscribe a circle with a radius equal to half of one of its sides; within it construct the two equilateral triangles, *a a a*, as in figure 50, forming by the intersection of their sides the hexagon *c c c*, &c. Bisect the arcs *a a* in *b;* join the alternate points *b* to form the two other equilateral triangles, *b b b*, &c., in which the dotted lines must not be inked in. Within the four triangles the dodecagon, *e e e*, &c., is formed, to the angular points of which draw the radial lines O *e*, O *e*, &c.

Exercise.—See Introduction 3.

FIGURE 53.

Draw the square C D E F, inscribe the circle, and within it construct the four equilateral triangles as in the previous), thus obtaining the series of points *a b c* and *d*. From the centre O draw radii to the points *a*, passing through *c*. Parallel to the sides of the triangles, *a a a* and *b b b*, draw the lines *c e*, stopping them at their intersection with the next diameter. Draw also the short lines *e f* to their intersection with the lines *c e*, and the outline of the star is formed. Draw *c g* parallel to the sides of the triangles, stopping them at *g* in the outline of the star.

The lines not lettered must be drawn parallel to, and equidistant from, the inner and outer sides of the system of triangles, and care must be taken to stop them at their junction with the radii O *a*, O *b*, &c., and also with the lines *a c*, *b c*, *c e*, and *c g*.

Exercise.—See Introduction 3.

FIGURE 54.

Construct the square E F G H, inscribe the circle, and construct within it four equilateral triangles; letter the points *a b c d e* and *f* as on the diagram; draw also the diameters *a a* and *b b*, and all the lines which are so far determined, exactly as in the previous figure. For the rest produce the lines *c d* to *g*, making *d g* equal to *c d*; draw *g a* and *g b*, and connect the points *g* with the points E F G H.

Exercise.—Draw the above figure, making the sides of the square E F G H 7 inches in length.

PLATE XIII.

FIGURES 55 TO 57.—*Designs of which the pentagon and decagon are the elements.*

FIGURE 55.

Draw a circle with any radius, and within it construct the pentagon A B C D E. (See figure 15, Plate III.) Find the points F G H J K, and construct the decagon. Draw the diameters A J, G D, B K, H E, and C F, bisecting the sides of the pentagon in the points *a b c d* and *e*. Connect these points, and the second pentagon is formed. The sides of this pentagon are likewise bisected by the diagonals in the points *f g h i j*, and lines drawn between them form the third pentagon. By continuing this process the pentagon *k l m n o* will also be formed.

Exercise: Draw the above within a circle whose diameter is 15 centimetres in length.

FIGURE 56.

Draw the centre line *a b* equal to twice the diameter of a circle of any convenient size; divide it into four equal parts in the points 1 A and 2. Through *a* and *b* draw the lines *c d* and *e f* at right angles to *a b*, each equal to *a* A, and so placed as to be bisected by *a b;* draw also *d e* and *c f*. From the points 1 and 2 as centres, and with the radius 1 A and 2 *b*, describe circles touching each other at the point A; within these circles construct the pentagons A B C D E and A F G H I. From all the angular points draw lines to the centres 1 and 2, constructing the inner pentagon *g g g* &c. parallel to the sides of the first, and at a distance of one-seventh of the diameter of the circle, and produce two sides of the pentagon *g h* to the points *h*. The parallel lines between the outside and inside lines of the pentagon must be drawn at a distance from them equal to one-fifth of that between the lines C D and *g g*. To complete the figure produce the radii *g* 1 to the points *i*.

Note.—In the above figure containing one pentagon band, the width of the latter *o i* may be taken *ad libitum*; but if there are two bands, the one interlaceing the other, as in figure 57, their width is determined, and is found by the following method. After having drawn the outside of the pentagon A B C D E, find the points *a n n* for the second; draw it as indicated by the dotted lines, and bisect its sides in the points *x*. Bisect also the sides of the first pentagon in the points *o*, draw *o o* and *x x*, and *x x* will be the interior sides of the first pentagon, intead of *g g*, and *o o* those of the second.

Exercise 1.—See Introduction 3.

2.—With a diameter of 8 centimetres for the circle, draw the above design twice, the one attached to the other so that the last line of the first, H G, forms the first line of the second.

FIGURE 57.

Draw the centre line *a b* equal to 66 units of a scale of equal parts; on either side of it, and at a distance of nine parts, draw the parallel lines *c e* and *d f*, and *c d* and *f e* at right angles to *a b*. From *a* and *b* mark and number the distance of 9 parts by 1 and 4, and from the latter points the distance of 16 parts in 2 and 3. Bisect the distances between 1 and 2, 2 and 3, and 3 and 4 in the points *n*, and through these points draw *g h*, *i j*, and *k l* parallel to *d c* and *f e*.

From the centre 1, and with a radius 1 *n* equal to 8 parts, describe a circle, and on it find the points *n* and *m* of a regular decagon. Draw two regular pentagons by uniting *n n* and *m m*, as shown by the dotted lines. On each side of these lines, and at a distance of one-fourteenth part of the radius of the circle, draw the parallel lines *p p*, making thus the whole breadth of the interlacing bands equal to one-seventh of the radius. From the centre 1, and with a radius of half of the radius of the large circle, draw the circle *s s s*. Divide the distance *s* 1 into 5 equal parts and draw the circle *t t t*, with a radius of three-fifths, and that marked *u u u* with a radius of one-fifth of *s* 1. The distance of the double lines of the three centre circles is equal to one-fifth the distance between these circles. From the points *r* draw the lines *r s* towards the centre 1. Find the points *t* by drawing lines from *m* and *n* towards the centre 1, intersecting the second circle in the points required. Draw *t s* to the inner line of the circle *s s*, also the lines *t u*, which will complete the figure about the centre 1.

The other parts 2, 3, and 4, are constructed in the same manner, and are joined one with another as shown on the plate.

Exercises: 1.—See Introduction 3.

2.—Draw only 3 parts, the third exactly like the second; the whole design to be 12½ inches long and 4½ inches wide (length 50 parts and width 18, each part ¼ of an inch).

PLATE XIV.

FIGURE 58.—*Ornamental pavement, or panel with plaited bands.*

Construct the rectangle A B C D, with a length of 41, and a width of 29 equal parts. On the sides of this rectangle the divisions o, ½, 1, 2, 3, &c., must be made for obtaining the points from which the lines of the design must be drawn. The points *o* are at a distance of half a part. Draw lines from *o* to *o*, so as to form the rectangle *a a a a*. Divide the longer lines between *o* and *o* into 40, and the shorter into 28 equal parts, and number them as shown on the plate. From the points 7 draw lines parallel to the sides of the rectangle, to the opposite sides, forming by their intersection the interior rectangle *b b b b*. In a similar manner construct the rectangle *c c c c* by drawing parallel lines through the points 9, and subdivide it by the lines *d d* and *e e*, drawn through the points 13 and 15.

To obtain the *plaited border* draw lines parallel to the sides of the rectangle through the points ½ and 6½, which form its boundaries. Draw the slanting lines from points 2 to 2, 3 to 3, &c., as shown on the plate, the auxiliary lines indicating the direction in which they have to be drawn from the numbered points.

The *plaited figure* in the centre must be drawn after the small squares, placed diagonally, are formed. The construction of this central figure, as well as the rest of the design, requires care in counting, but no further instruction.

Exercise.—Draw the above design, making one of the equal parts 6 millimetres in length.

PLATE XV.

Figure 59.—*Four rings and a band interlacing with each other.*

Draw a square A B C D of any convenient size, and diagonals intersecting each other in the point 1. Bisect the sides in the points *n*, and through these points draw lines parallel to the sides of the square. From 1 as centre, and with the radius 1 *n*, describe the circle *n n n*. Produce 1 *n* in all four directions to the points 2, making *n* 2 equal to 1 *n*. Connect the points 2 by lines passing through the points A B C D. From the points 2 as centres, and with the radius 2 A, draw the arcs A *b* B, B *b* C, C *b* D, and D *b* A, intersecting the circumference of the circle in the points *a a*, forming thus the outer lines of the figure *a a b a a*, &c. The inner arcs must be drawn from the same centres, with a radius equal to 2 *b* plus one-fifth part of the line 1 *b*.

To draw the rings bisect 1 *b* in 3, and with the radius 3 *b* describe from 3 the inner circles of the four intersecting rings, and describe the outer from the same centres with a radius one-fifth of 1 *b* longer than 3 *b*—the same breadth as that of the bands. The double lines are at a distance of ¼ of the bands from each other.

Exercise.—Draw the above, making the sides of the square A B C D 6 inches long.

Figure 60.—*Gothic balustrade or panelling.*

Draw the centre line *a b*, and at a distance of five equal parts from it, draw the parallel lines *c d* and *e f*, of any length required; at a distance of half a part draw a line parallel to *a b* on each side of it. Draw *c e*, intersecting *a b* in *r*. From *r* mark off on *a b*, at a distance of nine parts, the other points *r r*, and as many as may be required; bisect each of the distances *r r* in the points 1, 2, 3, 4, &c. From the points *r*, 1, 2, 3, &c., as centres, and with a radius equal to four and a-half of the parts, describe circles cutting each other. From the same centres, and with radii equal to four and five parts respectively, draw the inner and outer circles, taking care to stop them at their points of meeting with each other, and with the parallel lines of the centre bar. To finish the figure draw mitre joints (the cross lines at the junction of the ribs).

Exercise.—Draw the above, making it the length of your paper and 54 millimetres wide (one of the equal parts being six millimetres).

FIGURE 61.—*Gothic balustrade or panelling.*

Draw the centre line *a b*, and at a distance of four and a-half equal parts the parallel lines *n n* and *o o*. Draw *c c* at right angles to *a b*, and parallel with it, and at a distance of nine parts, the lines *d d*, *e e*, *f f*, *g g*, *h h*, forming thus five equal squares. Bisect them by drawing the lines *m m*, and mark the points *r*. From the points *c*, *d*, *e*, *f*, *g*, *h*, as centres, and with a radius equal to *c r* or *d r*, draw arcs meeting in the points *r*. On both sides of all the lines thus formed draw parallel lines at a distance equal to half of a part, stopping them at their points of meeting with each other, and draw the mitre points, as in figure 60.

Exercise.—Draw the design, making it 11¼ inches long and 2¼ inches wide. (One part is equal to quarter of an inch.)

PLATE XVI.

FIGURE 62.—*Gothic panel or grating in metal.*

Draw the rectangle A B C D (represented on the plate by the *second* lines *a b*, *c d*, *e f*, and *g h*), making its length equal to twelve, and its width equal to eight parts, and numbering the divisions from the angles to the middle of the lines, as on the plate. Through all these points draw lines 1 to 1, 2 to 2, &c., parallel to the sides of the rectangle, in both directions, forming thus a series of squares. Through the latter draw both diagonals from one side of the rectangle to the other, and through their intersection with each other the centres of the circles are obtained. Within the rectangle formed by the lines from 1 to 1, and with a radius equal to *one* of the divisions, draw from these centres the circles, which will touch each other at four points of their circumference. On both sides of these lines (called the *ridge lines*), and at a distance of one-ninth of one of the parts, draw parallel lines; in a similar manner draw lines on both sides of the straight lines which form the crosses within the circles, and on both sides of those in the borders, taking care to stop them at their points of junction with each other. For the *small circles* within the square at each corner of the border, make the radii one-ninth, two-ninths, and three-ninths of one of the parts respectively. At last draw the *mitre joints.*

Note.—Great care must be taken to draw the circles correctly so as to prevent jarring at their points of junction. The beauty of this delicate design depends entirely on accuracy and neatness.

Exercise.—The length of a panel is 6 feet, its width 4; in it draw the above design at a scale of 2 inches to the foot.

PLATE XVII.

FIGURE 63.—*Design for an inlaid table top.*

Describe a circle *x x x,* with a diameter of $0^{m}\cdot20$, representing a table five feet in diameter, the scale of equal parts being four centimetres to a foot. From the same centre, and with a radius of half the length of that of the previous circle, describe the dotted circle *a b a b,* &c. In the circumference of this smaller circle find the points *a*, *b*, *a*, *b*, &c., being the angular points of a regular duodecagon inscribed in a circle. (See figure 12, Plate III.) From all these points draw diameters *a* to *a*, *b* to *b*. Construct the two equilateral triangles *a a a* by lines drawn from *a* to the next but one *a*, in the circumference of the inner circle. On lines drawn between every two adjacent points *b* as bases, erect the equilateral triangles *b c b*, and from the points *c* as centres, and with a radius equal to *c b*, describe the arcs *b d b*, intersecting the diameters *a a* in *d*. Between the points *d d* draw lines parallel to the sides of the equilateral triangles *a a a*, thus forming their inner lines.

From the points *c* as centres, and with a radius equal to *c b*, plus the distance between the outer and inner lines of the equilateral triangle, describe the inner arcs of the figure *b b b*. The parallel lines within each band measure a quarter of the width of the bands.

For the construction of the *star in the middle*, describe, from the points *d* as centres, and with the radius *d i*, the arcs *i n i*, intersecting the diameters *a a* in the points *n*; between these points describe the arcs *n n* from the centres *d*, and with the radius *d n*.

The diameters of the *small circles*, placed between the points *i i* of the star have the length of the width of the bands of this star.

Draw all round the figure the *parallel lines* *g h* and *h g*, at a distance of half the width of the bands of the equilateral triangles, and the central figure is completed.

To finish the *zigzag* that interlaces with the *serpentine band*, construct on lines drawn between every two adjacent points *a* as bases, the equilateral triangles *a e a*, and through the intersection of the lines *e a* with *c b* in *f* one line of the zigzag *c f*, *e f*, &c., is obtained. The *lines parallel* to it are at a distance equal to the width between the lines *g h g* and *b d b*.

To construct the *serpentine band* draw arcs from all the points *f* as centres, and with a radius of one-third of the lines *f e* or *f c*; describe others, also, in a contrary direction from the points *e* and *c* as centres and with a radius of two-thirds of *f e* or *f c*, meeting those previously drawn. The outer arcs of the serpentine band must be drawn from the same centres at a distance from the inner equal to the width of the zigzag band.

In describing the circles of the outer border of the table, make the distance *x n* equal to the width of the serpentine band *m m*, and *n o* equal to half of *x n*, and lastly *o p*, again equal to *x n*.

PLATE XVIII.

FIGURE 64.—*Design for an embossed book or album cover.*

Make the rectangle A B C D, with a length of 43, and a width of 28 equal parts of, say a quarter of an inch each, and number the divisions as on the plate.

Through the points 8 draw *g g* parallel to the sides of the rectangle, forming, by their intersection, the inner rectangle *e e e e*. Through the points 14 in A D and B C, and through 21½ in A B and D C, draw the lines E F and G H, making the latter of any indefinite length. Through 6½ draw the four lines *a a* intersecting E F in *b b*, and G H in *c c*; the distance *b b* will be the length of the major axis, and the distance *c c*, the length of the minor axis of the large *oval*, which must be constructed according to directions for figure 27, Plate IV. The divisions of the line *b b* into 6 equal parts are lettered *o*, *d*, *d*, *r*, *r*, corresponding to E, *a*, *a*, 1, 1, of figure 27. The *smaller oval* in the centre is to be constructed according to directions for figure 22, Plate IV.; its larger axis *f f*, corresponding with A B, its smaller one *d d*, with D C, its centres *m*, *m* with 1, 1, and the centres *n*, *n* with 2, 2. For the construction of the *circles*, make the distances *b h* equal to *c f*, and the radius *r h* is obtained. The sides of the *triangular figures z z z* must be drawn parallel to the ovals and circles respectively, at a distance from them equal to *b h* or *c f*.

For the construction of the *plaited border* draw through all the divisions on the sides of the rectangle slanting lines, as indicated by the auxiliary lines. To avoid confusion, draw first the four lines from points 14 on A D and B C, to the points 14 on A B and D C. All the rest of the slanting lines must be parallel to one or the other of these.

For describing the *arcs* of the *circular portion* of the bands, draw the lines *p p* through the points 2½, and *q q* through the points 4½, on all four sides, and the points of intersection of these with the slanting lines will be the centres for the arcs.

The inner parallel lines of the ovals, circles, triangular figures, and bands of plaited borders may be drawn at a distance of one-fifth of the width of the bands of the border.

PLATE XIX.

The figures in this plate have two objects. First, to show what a variety of interesting figures, besides those already described, may be composed of the elements contained in the first four plates. Few and simple as these elements are—they are virtually only the straight line and the circle—there is really no limit to the number of designs and to the variety of forms that may be composed of them; just as nature produces, with a few chemical elements only, all the endless and beautiful diversity in the vegetable kingdom. Secondly, to afford the pupil the opportunity of exercising his own skill and powers of reflection in discovering for himself the manner in which certain figures are to be constructed on a larger scale. Consequently, only a few hints are given for the construction of most of these figures, and for some none at all.

FIGURES 65 TO 77.—*Studies of various combinations or designs composed of the elementary figures contained in the previous plates and exercises.*

FIGURE 65.

The basis of this figure is the pentagon. (See figure 15, Plate III.) The width of the angular interlacing bands *a a a* is obtained by the intersection of the lines *a n a*, with diameters drawn from the next point *a* to *b* on the opposite side of the circumference. The manner in which the centres for describing the arcs *b b* are obtained is indicated by the dotted lines; *b r* is equal to *b b*. The width of these bands is equal to that of the angular bands; half the width is to be put on each side of *b b*. (Compare this figure with that within the zigzag of figure 63.)

FIGURE 66.

The basis of this figure is the *hexagon*. (See figure 12, Plate III.) The centres *r* for the arcs of the figure are obtained by the intersection of the sides of two equilateral triangles, *a a a* and *b b b*, with the radii O *a* and O *b*.

FIGURE 67.

The basis of this figure is the *octagon*. (See figures 13 and 14, Plate III.) First letter the points of the octagon; draw the diameters, and also the lines *a b*, *d c*, &c., and through the intersection of the latter with each other are obtained the points *n*, through which the inner lines are to be drawn parallel to them. To obtain the radii of the circles for the circular band *m m* divide *a n* into three equal parts, and the distances from the points of division to the centre are the radii.

FIGURE 68.

The basis of this figure is again the octagon. Find all the points *a*, *b*, and *c*, draw radii from the centre to these points, and the lines *a n b*, *b n a*, &c., intersecting each other in *n*. Through these points draw lines parallel to *a n*, *b n*, &c., forming thus two interlacing angular figures. The centres for the arcs *c c* are the angular points of the two squares round the figure. The width of these bands is the same as that of the bands of the angular figures.

FIGURE 69.

The basis is again the *octagon*. Find the points of the octagon, and describe squares *a a a a* and *b b b b* through the points 1 and 2. Draw diameters from 1 to 1, and from 2 to 2. Produce the sides of the squares till they meet each other; their points of intersection are the centres of the inner arcs 1–2 and 2–1. The width of the border is optional.

FIGURE 70.

The element is the *equilateral triangle* in a circle. Draw radii from the centre O to the points *a*, and mark off on them any desired width O *b* of the bands. From each of the points *b* draw lines to the two points *a* in the opposite half of the circle; bisect them, and erect on them, at the points thus found, perpendiculars, intersecting each other in *r*, the centres of the arcs *a b a*.

FIGURE 71.

Requires no explanation.

FIGURE 72.

The element—*the hexagon*.

The centres of the arcs may be found either by the method employed in figure 70, or by describing the inner circle *a a a* and dividing it into six equal parts to get the points *r*, which are the centres for describing the arcs *r* O *r* with the radius O *a*.

FIGURE 73.

Requires no explanation.

FIGURE 74.

Divide the circumference of any circle into sixteen or any other number of equal parts; draw radii to the points thus obtained, bisect them, and the points of bisection are the centres for the radial semicircles.

FIGURE 75.

Through the centre of any circle draw a diameter *a b*, and divide it into eight equal parts. Bisect the two first parts on each side of the centre, and number the parts right and left from the centre 1, 2, 3, 4, 5. From the points 1 to 4 as centres, and with radii equal to the distances of 1, 2, 3, 4 from the centre respectively, describe the small semicircles; then return towards the centre, describing from the points 3, 2, and 1 the radial semicircles.

FIGURE 76.

This is an *interlacing of two flat oval rings.* The centres of the arches are the angular points of the square *a a a a.*

FIGURE 77.

Two *flat circular bands*, seen in an oblique position, thus offering to the eye two oval figures. The ovals may be made by the method used for figure 22, but care must be taken to place the axes of each pair of ovals, *a a*, *b b*, at a distance from each other equal to that of the width of the bands. Join the ends of *a b* by a straight line.

FIGURE 78.—*A chain border.*

Its construction is indicated by figure 78′, in which the points *a a* in the small square are the centres of the arcs required. Figure 71″ is the beginning of a modification of the chain, the additional centres for the small arcs being the points *b.*

FIGURE 79.—*A flag staff with a streamer.*

Figure 79′ shows its construction, the centres of the arcs being the points *a* and *b* in the squares. Figure 79″, is a modification of it, caused by the introduction of a second serpentine streamer between the first.

C.—PLATES XX.-XXIV. FIGURES 80-100. APPLICATION OF LINEAR DRAWING TO EASY SCIENTIFIC, ARCHITECTURAL, MECHANICAL, AND ENGINEERING PURPOSES.

PLATE XX.

Elementary geographical, and astronomical diagrams.

FIGURES 80^a and $80b$.—*Geometrical projections of the terrestrial globe.*

FIGURE 80_a.

This diagram shows the geometrical projection of the northern half of our globe on the plane of the equator. The centre N of the figure represents the *North pole*; its circumference at the base the *equator*. The concentric circles represent *parallels of latitude*, and the dotted circles the *Arctic circle*, and the *Tropic of Cancer*. The parallels of latitude are drawn at a distance of ten degrees from each other. The lines radiating from N to the circumference represent *meridians* (lines of longitude). The line N O represents the *first meridian*, and passes through Greenwich. The meredians to the right of the first indicate *east* longitude, those to the left of it, *west* longitude, up to 180 degrees respectively.

On the *circumference* the distance between every two meridians represents ten degrees, or two nautical miles, of upwards of 6,000 feet each.

As the distance between the meridian lines diminishes towards the north pole, the length of a degree of longitude also diminishes. In the latitude of London the length of a degree of longitude is about 37 nautical, or 42½ English miles.

FIGURE 80^b.

This diagram represents a geometrical projection of half of the terresterial globe, on a plane passing through the poles. The part above the line representing the equator corresponds with the previous diagram, figure 80^a. The other part, *south* of the equator, is similar to the upper portion. The lines drawn from pole to pole, all but one being curved, represent the *meridians*, and correspond with the radial lines in figure 80^a; the lines parallel to the equator represent the *parallels of latitude*, and correspond with the concentric circles in previous figure; the dotted lines represent the *Arctic* and *Antarctic circles*, and the *tropics*.

Both figures should be drawn at the same time. Describe two circles with a diameter of about four inches, divide each circumference into four equal parts, and subdivide each into nine equal parts. From the points thus obtained draw in figure 80^a radial lines to the centre N, representing the *meridians*. In figure 80^b from the points of division draw lines parallel to that representing the equator. These are *parallels* of *latitude*.

The length of the radii of the concentric circles in figure 80^a is half the length of the corresponding *parallel of latitude* in figure 80^b.

To obtain in figure 80^b the points on the *equator* through which the curves must be drawn from pole to pole, either drop perpendiculars upon the *equator* from the *parallels* of *latitude* at their meeting with the circumference, or lay down the lengths of the corresponding radii of the concentric circles in figure 80^a. These curves, representing the *meridians*, are drawn in the diagram as arcs of circles; in reality they are elliptical. To obtain the centres for describing these curves, draw lines from the points of intersection of the meridians with the equator to either of the poles. Bisect these lines and erect perpendiculars at the points of bisection, producing them to meet the equator. Their points of intersection with each other are the centres of the curves. The mode of finding the dotted lines representing the *Arctic* and *Antarctic* circles and the *tropics* will be explained in the next figure.

FIGURE 81.

Describe a circle of the same size as that of figures 80^a and 80^b; draw W E and N S. Through the point o draw the dotted line *a b* at an inclination of 23° 27′ to the equator, representing the sun's *ecliptic.* From the extremities of this line in *a* and *b* on the circumference, draw lines *a f* and *b g* parallel to the equator, they will represent the lines of the *Tropics.*

Through the point o draw a line at right angles to *a b*, meeting the circumference in *e* and *d*. Draw *e h* and *d i* parallel to the equator; these lines represent the *Arctic* and *Antartic circles,* and are 23° 27′ distant from the poles, or 66° 33′ north and south of the equator.

Now insert in figure 80^b the Arctic, Antarctic, and Tropical lines, and with radii equal to half the lines representing the Arctic Circle, and the line of the Tropic in figure 80^b, describe, in figure 81^a, the Arctic Circle and the line of the Tropic.

FIGURE 82.—*The Mariner's Compass.*

Divide the circles into quadrants, and mark the points N. S. E. W. Divide each quadrant into eight equal parts, and the 32 points of the compass are obtained, the distance between any two points being 11° 15′. Each point is divided into four parts, called *quarter points.*

Figure 83.—*The ellipse.*

Let A B and C D be the longer and shorter diameters. Let them bisect each other at right angles in E. From the points C and D, with a radius equal to half A B, describe arcs intersecting each other in F. The points F are the *foci* of the ellipse. From each of these points, with a radius equal to F F, describe arcs on both sides of A B; from F as centres, and with a radius equal to twice A F, draw arcs intersecting the previous ones in *a;* these points are in the circumference of the ellipse. To find any other points, say *b*, draw arcs from F as centres, with a radius of any length greater than F C; deduct the length of the radius just employed from the total length of A B, and with the difference as radius, describe from F arcs intersecting the previous ones in *b*. Draw arcs carefully between these points, and the ellipse is obtained. The greater the number of points, the more easily will the figure be drawn.

Figure 84.—*The Planet Saturn with its rings.*

Draw the larger ellipse A B C D as shown above, making the proportion of the larger diameter to the smaller one equal to that given in the diagram. Determine in the same manner the diameters *a a*, *c c*, *e e* of the inner ellipse; draw A D, and parallel with it, from *a c e* the lines *a b*, *c d*, *e g*, meeting E D in *b*, *d* and *g*, and E *b*, E *d*, and E *g* are respectively half of the smaller diameters of the inner ellipse.

Figure 85.—*Side view of the relative positions of the Earth and the Sun at the four seasons.*

This diagram requires no explanation.

PLATE XXI.

Ground plan and Elevation of a small railway station.

These plans are drawn, as noted at the foot of the plate, at a scale of one-eighth of an inch to a foot, but must be drawn by the pupil at a scale of quarter of an inch to a foot. The dimensions of the various parts are marked in feet and inches, the distances to which they apply being indicated by light lines terminated by the head of an arrow. Thus, for instance, the openings between the pillars of the arcade are marked <—— 4′ 10″ ——>, meaning that their width is 4 feet 10 inches.

FIGURE 86^a.—*Ground plan of the station.*

By adding up the dimensions, marked at the outside of the building, it will be found that the rectangle forming the ground plan is 43 ft. 4 in. long, by 28 ft. 4 in. wide.

Draw this rectangle and bisect it by the line *a b*. From this line, and from the line *l m*, which represents the side of the building facing the railway, all the parts of the plan must be measured off. As a general rule the centre line of the various openings, and the prominent lines of the angles of the various portions, should first be drawn.

In this plan, for instance, measure off from the centre line *a b*, on the line *n o*, 9 ft. 4 in. on each side, thus obtaining at the points *c c* the breaks in the line of the front wall. These breaks are 5 in. wide, therefore the front line of the arcade wall must be set back that distance from the line *n o*. Inside the outline of the plan, and at a distance of 14 in., draw parallel lines all round the figure, and the outside walls will be represented. From these lines draw the partitions according to the indicated dimensions; for instance, the length of the waiting-room and luggage-office is 15 ft. 6 in. measuring from the wall *l m*, make the thickness of the partition equal to

6 in., and a width of 9 ft. 7 in. is left for the interior of the vestibule.

For the partition walls of the small *waiting-room* draw lines at 5 ft. on each side of *a b*, and make the thickness of the walls 6 in. In the *vestibule* measure off on each side of *a b* a distance of 10 ft., where walls 6 in. thick must also be drawn. The width of the staircase is 6 ft. 8 in., and the partition wall between it and the w.c. 4 in. thick, leaving a width of 3 ft. for the w.c. The openings for the doors, fireplaces, &c., can now easily be marked off in the various partitions. To draw the *openings* in the *outside walls* for the arcade, windows, &c., measure off on the lines *a b* and *l m*, from the *centres* of these openings, half their width on each side of the centres. The completion of the plan presents now no difficulties.

FIGURE 86B.—*The Elevation.*

Draw the ground line A B and the centre vertical line *a b* at the same scale as in the Ground plan. Draw J K, representing the height of the front of the building, parallel to A B, and at a distance of 23 ft. from it. On each side of *a b*, and at a distance of 21 ft. 8 in., draw the vertical lines *e f*, and at a distance of 9 ft. 4 in. the lines *c d*. Bisect the distances *c e* in *g*, and draw the vertical lines *g h*. At a distance of 6 ft. on each side of *a b* erect the vertical lines *i k*, and all the angular lines of the building, as well as the central lines for the openings, are obtained. At the proper distances draw the lines C D, E F, and G H, parallel to A B; draw also the line L M, the lower line of the *string course*, between the ground floor and the first story.

For the openings on the ground floor draw, at a height of 7 ft. from the *plinth* line C D, a line parallel to it; this is the *springing line* of the *arched openings*, and its intersection with the vertical centre lines in the points *o* are the centres of the arcade and side windows. By proceeding in the same manner the height 5 ft. 7 in., and the width 3 ft. 6 in. of the openings on the first floor will be obtained. The *sill* is 2 ft. above the string course E F, and the *architrave* round the openings of the window is 5 in. wide. The remainder of the drawing needs no further explanation.

PLATE XXII.—BRIDGES.

FIGURE 87.—*Arched bridge over a canal with two side roads.*

This and the following figure are drawn at a scale of five millimetres to the metre, but must be drawn by the pupil at a scale of one centimetre to the metre.

Draw the line A B for the level of the ground and of the road on each side of the canal, and at a height of $7^{m}\cdot5$ draw C D, representing the level at which the road or railway is to be carried over it. Let the line *a b* pass through the centre of the canal and of the bridge; on each side of it measure off on A B a distance of 7 metres for the top width of the canal; two metres lower, draw a line parallel to A B, of a length of four metres on each side of *a b*, representing the bottom, and draw the sides of the canal.

Parallel to *a b*, and at a distance of $6^{m}\cdot9$ on each side of it, draw lines representing the projecting angles of the abutments of the large arch. At a distance of $11^{m}\cdot7$ on each side of *a b* draw the lines *c d* for the centre lines of the side arches. The line for the *springings* of the arches is 3^{m} above A B, between which and A B, at a distance of 6^{m} on each side of *a b*, draw lines parallel to the latter. Similar lines must be drawn at a distance of 3^{m} from the lines *c d*. The radius for the semicircles is 3^{m}, the width of the *arch-stones* 60 centimetres.

For the construction of the central arch, which is half of an oval, see figure 27, plate IV., where the centres required are marked *o*. The width of the *arch-stones* is 90 centimetres.

The under side of the *cornice* is a line drawn parallel to, and 7^m above A B. The height of the *parapet* is 1^m. The *ornamental railing* must be drawn according to figure 60, plate XV., leaving out the central bar and the double lines. The projecting towing paths are indicated by P P. The height of the *courses of stones* at the angles in this and the following figure is half a metre, the lengths alternately 60 and 90 centimetres. The height of the stones in the *facing courses* is half that of the others.

FIGURE 88.—*Iron girder bridge.*

This figure is of the same dimensions as the last, the absence of intermediate piers being its recommendation.

Draw the lines A B, C D, and *a b* as in previous figure. Parallel to, and at a distance of 15 metres on each side of *a b* draw vertical lines for the face of the abutments. At a height of $5^m{\cdot}3$ above A B draw the parallel line *c d*, representing the under side of the girder, and 3^m above this draw another parallel for the upper side of the girder, this gives the width of the girder, which is one-tenth part of the span—the usual proportion in such bridges. The construction of the remainder of the figure presents no difficulty.

PLATE XXIII.

Examples of applied physical and mechanical science.

The diagrams are drawn to various scales, and must be enlarged when reproduced, due proportions being preserved in all the parts.

FIGURE 89.—*The Spirit-level.*

This instrument is used by mechanics to ascertain whether a surface is horizontal. *a a* is a brass plate upon which is fixed the ietal tube *b b*, containing a glass tube slightly curved in the middle, and divided into any number of equal parts. The glass tube is very nearly filled with coloured alcohol, the remaining space being filled with a small quantity of air marked *n*. When the level rests with the air bubble in the middle, as indicated in the diagram, the plate *a a* is perfectly horizontal.

FIGURE 90.—*The Water level.*

This instrument is used in measuring the undulations of extended surfaces.

a a is a brass tube upon which are fixed two glass bottles containing water and communicating through *a a*. The point *c* represents a metal cup fitting to a tripod wooden stand about 4 feet high. When the instrument stands at rest upon a horizontal surface, the water in the bottles stands at *b b*, and the line joining these points is horizontal. When it stands at rest upon a *sloping surface* the water still assumes a horizontal position in the bottles, and the change of level is measured by means of the line *b b*.

FIGURE 91.—*Application of the Lever of the first kind.*

FIGURE 92.—*The Wheel and Axle.*

Draw two circles touching each other, the radius of the one being one-third of that of the other. Nearly half the length of the teeth must be on each side of these circles, *pitch circles*, as they are called, the outer half being a little shorter than the inner.

FIGURE 93.—*The Inclined Plane.*

The part A on the left represents a waggon drawn up by a rope passing over a drum C at the top of the plane.

The part B represents a waggon propelled by steam, applied to a mechanism similar to that in Figure 92, working on a toothed rail or rack laid up the middle of the road.

Both these inclined planes have a rise of "three in ten," that is, for every ten feet in the length of the plane there is a rise of three feet in height. The system B is applied on mountain railways.

Figure 94.—*Fusee of a watch.*

a is a *cylinder* containing a *spring;* to this cylinder is attached the chain from *b*, the *fusee* of the watch. In winding up the watch we coil the chain round the fusee, beginning at the largest part of it, and going on to the smallest. At the same time the spring in the cylinder has been wound up to its full force by the chain. In that position the tension of the spiral spring within the cylinder is greatest, and draws the chain gradually round the cylinder, unwinding it from the fusee. The augmentation of the leverage on the fusee from the top towards the bottom, proportionate to the increase of its diameter, compensates for the diminution of force in the spring, as it gradually uncoils, and a uniform motion is thus obtained.

Figure 95.—*A timepiece.*

The pupil is recommended to draw at a convenient scale the front view of any timepiece that may be within his observation, beginning with the diameter of the dial. The dotted lines show the manner of finding the centres for describing the circular portions of the diagram.

Figure 96.—*Anchor escapement of a clock.*

This mechanism regulates the motion of the clock. Diagram A is a geometrical side view, showing the connection of the escapement with the pendulum; diagram B is a front view of the anchor and the escapement wheel. The corresponding parts in both diagrams are indicated by the same letters.

The vibration of the pendulum *a* communicates its movement to the forked bar *d e f*, which is fixed on the axis *f g*, giving it thus a rocking movement. During each movement *one* of the teeth of the wheel *i i* escapes alternately in either of the points *n n*, hence the name *escapement*. The rotation of the wheel *i i* thus regulates the movements of the whole work of the clock.

FIGURE 97.—*The Barometer and the Thermometer.*

As a model for the case of the barometer the pupil should take any barometer that may be within view. The dotted lines show the manner of finding the centres for the circular portions of the case.

The diagram on the left represents the glass tube containing the mercury, and the *modus operandi* of the hand. To a thread passing round the axis A is fixed at each end a small glass bulb filled with mercury, the one dipping into the glass tube being heavier than the other. With each rise or fall of the mercury in the glass tube, the glass bulb dipping into it rises or falls to a similar extent, and moves the axis on which the hand is fixed.

In the little thermometer at the upper end of the instrument, the divisions into degrees may be made according to the scale of Fahrenheit, Reaumur, or Celcius; the last is called *centigrade*, because the distance between the boiling and freezing points is divided into 100 parts or degrees.

FIGURE 98.—*The hydraulic press.*

In employing this machine we take advantage of the facts that liquids are incompressible, and that they transmit pressure equally in every direction. If, for instance, pressure is applied to one square inch of the surface of a liquid, that amount of pressure is transmitted to every square inch of surface of the liquid, and the total amount of resulting pressure is proportionate to the total number of square inches that have been applied.

The part A A represents an iron cistern, to which is adapted a pump, the barrel of which dips into the water in the cistern. At the bottom of this barrel is a valve *c*, which at each upward stroke of the plunger *b* opens, and admits a certain quantity of water into the barrel. At the down stroke of the plunger this valve closes and the water is forced through the tube *d*, opens the valve *e*, and runs through the connecting tube *t* to the cylinder B.

Any pressure applied to the plunger *b* is communicated to the surface of the water in B, forcing upwards the ram *g* with a pressure so many times greater than the force applied to the plunger *b*, as the surface of the under side of the ram *g* is greater than the under side of the plunger *b*. For instance, let a force of 50 pounds be applied to the extremity *a* of the lever of the force-pump, and the amount of this pressure, through the leverage due to the distance of *a* from the fulcrum be increased four times, thus increasing the whole pressure to $4 \times 50 = 200$ pounds. Now let the areas of the under surfaces of the plunger and of the ram be respectively one square inch and 250 square inches, then the pressure applied to the ram is $200 \times 250 = 50{,}000$ pounds.

This is a machine of truly tremendous power, and is employed where great force is required; as, for instance, in pressing cotton. It was employed in raising the Britannia Tubular Bridge, when a steam engine was used for working the force-pump.

PLATE XXIV.—STEAM ENGINES.

FIGURE 99.—*Newcomen's.*

Newcomen's steam engine—the first applied to practical purposes in England, and here drawn to a scale of half an-inch to the foot.

Let A B be the line of the *surface of the ground.* On it erect the perpendicular *a a*, representing the axis of the well from which water is to be pumped, and at a distance of 10 feet 3 inches from it draw the perpendiculars *b b*, representing the axis of the ***steam generator*** and of the steam cylinder. Draw *c c* parallel to *a a* and equidistant from *a a* and *b b*. Measure off all the horizontal lines or heights from the line A B, and all the vertical lines from the centre lines *a a*, *b b*, and *c c*. The links of the chains on the plate are made by the interlacing of rectangles with each other. The drawing of the remainder of the diagram presents no difficulty.

FIGURE 100.—*The Rocket.*

The "Rocket," the first locomotive engine, constructed by George Stephenson in 1829.

Let A B represent the upper surface of the rails. At *a* and *b* erect perpendiculars at a distance of 2½ metres from each other, and at a scale of 10 centimetres to the metre. On these lines measure off the heights of half the diameters of the wheels. Through the centre of the large wheel, called the *driving wheel*, draw the line *c d*, finding first the angle which this line makes with A B. From the working lines thus obtained the drawing can easily be completed.

THE END.

LETTER FROM HENRY WEEKES, ESQ., R.A.,

LECTURER AT THE ROYAL ACADEMY.

2, Eccleston Street, Pimlico,
Dec. 27th, 1873.

Dear Sir,

I have examined the Text and Plates of your new work on Linear Drawing, and can, without hesitation, say that your object is a good one, as I understand it, namely, to lead the pupil through elementary geometry into ornamental design.

Few of our youths have hitherto been taught the immense value of the rule and compasses, and to what an extent shapes of the most fanciful kind may be produced by them alone.

The old gothic architects were great masters in the use of them, and hence the many beautiful forms we find in their works, combined with sound architectural constructiveness. The study of Linear Drawing of this kind, whilst it made them profound geometricians, led them gradually into art of a higher nature, and the consequence was that, when their hand was guided by the eye alone, it never departed from what was expressive both of beauty and fitness. Their line and rule, or, in other words, their geometrical knowledge, unconsciously governed their fancies, and so prevented them from becoming wild and absurd.

Every man should, in my opinion, be a geometrician, whether he be brought in contact with art or not, as it tends to give him that proper balance of mind necessary to sound thinking of all kinds.

Allow me to congratulate you on taking a step in the right direction, and to wish you all the success your attempt, so well carried out, deserves.

I remain,
Dear Sir,
Yours faithfully,
H. WEEKES.

G. C. Mast, Esq.

Price One Shilling.

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LONDON: CHARLES BEAN, 81, NEW NORTH ROAD.